AN EVALUATION OF
HABITAT POTENTIAL
FOR WILD RICE (Zizania palustris L.)
IN NORTHERN SASKATCHEWAN

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In Partial Fulfillment of the Requirements
for the Degree of
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by
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UNIVERSITY OF SASKATCHEWAN
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(*ZIZANIA PALUSTRIS* L.) IN NORTHERN SASKATCHEWAN.

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ABSTRACT

A multifaceted approach was used to obtain a first approximation of the distribution of capability, within the 297,000 km² northern Saskatchewan region, to support wild rice. Significant differences in habitat and growth performance were described and related to location. The least productive sites were found to be waters of lower nutrient status on the Precambrian Shield. Plants were also more robust in stream sites than lake bays, and an eastward or northeastward gradient of decreased production was noted in several habitat factors and measures of wild rice morphology. Accumulation of heat and light during the growing season was found to provide a basis for excluding one-third of the region as unsuitable. A broad classification of habitat potential was completed. Integration of plant - habitat relationships, with factors affecting the availability of suitable conditions, allowed general limitations to be identified. Approximately one-third of the region was considered to have moderate or high capability for providing wild rice habitat.

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Upper: Newly-established wild rice stand in a sheltered bay, general vicinity of the Precambrian Shield margin, west of La Ronge.

Lower: Open stand of wild rice (foreground and right), flanking shoreline bulrushes in the mouth of a small stream, southeast of Buffalo Narrows.

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Prologue

" The best indication for the moment, for the purpose simply of having a general idea of the wild rice potential, is the provincial land use statistics which show that 31,518 square miles or 12.5 per cent of the total area of the province is under water and is concentrated in the northern portion. Less the area representing the four largest lakes (7,762 sq. miles), there still remains 23,756 square miles or 15,203,840 acres. Assuming only one half of one percent (76,000 acres) is potentially very good and is accessible or could be made accessible in the next 10 years, it appears that there is substantial potential to warrant a serious economic development proposal. "

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A Feasibility Study on the Installation
of a Wild Rice Processing Plant in
Northern Saskatchewan

Economic Development Branch
Department of Northern Saskatchewan

March 1981

INTRODUCTION

Though not on the scale of wheat on the prairie, widespread introduction of wild rice has clearly added an important new dimension to the economy as well as to the aquatic environment of northern Saskatchewan. In a once-glaciated landscape characterized by a myriad lakes and streams the crop has generated much optimism. However, the ultimate extent of its proliferation, together with the social and ecological consequences, has thus far been a matter for speculation. The essential purpose of this study has been to contribute to an understanding of the eventual size of the wild rice industry and the possible spatial distribution of its impact. Initiated in June 1983, it was the first extensive investigation of the subject undertaken in Saskatchewan.

The principal goal has been to establish a biogeographical basis for evaluating wild rice production potential throughout northern Saskatchewan. This region is defined as having the Northern Administration District (NAD) boundary as its southern limit (Figure A). The research approach was multifaceted, employing a variety of techniques in order to accomplish the following objectives.

Figure A. The study region: northern Saskatchewan.

First, there was an examination of the plant in relation to its particular niche. The objectives were:

- to quantify variations in certain site conditions and wild rice performance in order to define suitable habitat;
- to determine if the Saskatchewan wild rice population consists of a single variety of the species;
- to test the hypothesis that location is important in accounting for variation in habitat and performance.

Second, there was an examination of general environmental heterogeneity within the region in terms of factors affecting intraregional wild rice habitat potential. The objectives here were:

- to determine whether a climatic limitation exists which would exclude wild rice from any part of the region;
- to develop a first approximation of the distribution of wild rice potential in northern Saskatchewan at the subregional level.

Chapter 1

ECOLOGY OF WILD RICE: A Review of the Literature

1.1 Taxonomy and Range

The contemporary common name "wild rice" applies to annual species of Zizania, one of 5 genera in the Zizanieae tribe of the grass family (Poaceae). A perennial species, Zizania latifolia (Turcz.) Stapf. (Manchurian water-rice), is native to eastern and southeastern Asia. This plant, with a chromosome number of 34, is readily conceded to be a separate species from the indigenous North American annuals whose chromosome number is 30 (Terrell and Robinson 1974; Hirayoshi 1956; Fassett 1924). A central Texas endemic restricted to the San Marcos River, Zizania texana Hitch. (Texas wild rice), is said to be perennial. However, its status is doubted by Dore (1969) in his detailed treatment of Zizania taxonomy. Four forms have been recognized within the annuals on the basis of morphology, range and habitats. Dore argued convincingly for 2 annual species, each with 2 varieties. He thereby disputed the nomenclature of Fassett who had proposed a single species, Zizania aquatica L., and 4 varieties.

This study adopts the botanical nomenclature of Dore (1969). Despite his point that, since the plant is not an escaped form of the Asian rice Oryza the common name should be written as "wildrice" or "wild-rice", the 2-word spelling remains predominant and will be used here. The exclusively riparian species Zizania aquatica L. includes the variety aquatica (Hitch.) Fassett (Southern wild rice), and the variety brevis (Fassett) Dore (Estuarine wild rice). A second species, Zizania palustris L. is comprised of the variety palustris Dore (Northern wild rice), and the variety interior (Fassett) Dore (Interior wild rice). Intervarietal hybridization is reported to occur in both species, producing morphologically intermediate types.

The range of wild rice may be broadly stated as eastern and central North America (Figure 1.1). Southern wild rice occupies rivers in a predominately near-coastal band from the Gulf of Mexico to Maine, while estuarine wild rice is restricted to the fresh water tidal zone at the mouth of the St. Lawrence River. Northern and Interior wild rice are found in the upper Mississippi - Great Lakes region, extending into the southern portion of the Boreal Forest. These latter two varieties are sympatric over much of their species' range, although a latitudinal gradation in dominance is acknowledged (Dore 1969; Lee 1979; Plansearch 1980; Oelke et al. 1982).

- *Zizania palustris* var. *palustris* & *interior*
- *Zizania aquatica* var. *aquatica*
- *Zizania aquatica* var. *brevis*
- *Zizania texana*

**Figure 1.1. Range of wild rice in North America
(after Oelke et al 1982)**

Zizania palustris is thus the most widespread species in Canada, and subsequent discussion will focus on its varieties. This is also the species of commercial value, owing to its large seed size.

Sporadic occurrences outside the general distribution, together with extensions at the margin of the natural range, are mainly deliberate introductions of the plant as a cereal or forage crop. In the United States the plant is now being grown in Idaho and, on a large scale in paddies in California (Winchell and Dahl 1984). In Canada the range has been extended into the Maritimes as well as northwestward into Saskatchewan and Alberta. However, even within its natural range wild rice stands are scattered and discontinuous. Aspects of distribution, range expansion and migration may perhaps be more fully understood from a discussion of wild rice ecology.

1.2 General Habitat Description

Wild rice is usually described as an aquatic grass. More specifically it may be classed as an anchored emergent macrophyte, indicating that it inhabits the littoral zone of lotic (fluvial) and lentic (lacustrine) environments (Wetzel 1975). Daubenmire (1968) considers such species to be

amphibious, in reference to their adaptation to existing concurrently in aquatic and "terrestrial" (supra-aquatic) environments. Emergent macrophytes are among the most productive in the biosphere because they are able to utilize the resources of both the aquatic (high nutrient and water availability) and terrestrial (high CO_2 , O_2 and light availability) components of their habitat. At the same time however, they must consequently be capable of tolerating certain environmental limitations imposed by each component.

Wetzel (1975) defines the littoral zone as extending from the point at which the water table is about 0.5 m below the soil surface, to the limit of growth of rooted submergent macrophytes at up to 3 m depth. Wild rice may occur from the seasonally-inundated (eulittoral) section to some point in the middle littoral section (Figure 1.2). The maximum depth range is from 0 to 2 m, provided that during germination there is at least temporarily some water. Interior wild rice inhabits the upper littoral and eulittoral sections, growing best at depths of 0.5 m or less. Seasonally fluctuating water levels, characterized by an early spring runoff peak and followed by a gradual steady decline through summer, often to zero, are considered optimal (Dore 1969; Thomas and Stewart 1969). Such a regime is typical of lotic waters and accounts for the colloquial name "river rice" for this variety.

Figure 1.2. Habitat of Zizania palustris L. varieties interior (l) and palustris (p) in relation to lacustrine zones (adapted from Wetzel 1975)

Northern wild rice, distinguished from the former by the colloquial name "lake rice", appears to be better adapted to the somewhat deeper waters of the upper to middle littoral sections, with an optimal depth range of 0.5 to 1.0 m. Although the varieties readily hybridize to produce intermediate types, careful scrutiny is said to reveal an outer band of predominantly Northern wild rice, grading shoreward to an area dominated by the interior variety (Dore 1969).

Despite the fact that wild rice grows in lakes and in some cases ponds, Dore (1969) stated that often the plant is found in lake-like expansions of rivers, or at the inlet of a stream feeding into a lake. He argued therefore, that it is mainly a riparian species, and that it will not persist in stagnant bodies of water. Steeves (1952) suggested that the internal currents within lakes may provide sufficient water circulation. Since wild rice is an annual, and is known to be a very poor competitor in association with perennial aquatic macrophytes, it follows that the species is adapted to regular recurrence of disturbance. Such disturbance is provided in streams and rivers by annual or periodic flooding and associated alluvial transport. Often wild rice stands in river channels and deltas clearly delineate the shape of the underlying silt bars. In lakes however, disturbance imparted

by currents alone is less significant. A combination of wave action, water level fluctuation and the uprooting action of ice dragging out emergent stems may function to maintain suitable conditions for sustained wild rice growth.

1.3 Life Cycle and Phenology

Growth is initiated in spring with the sprouting of previously-dormant seeds imbedded in the sediments. The dormancy is the result of the seeds' relatively impermeable coat and the presence of water-soluble growth inhibitors (Simpson 1966; Cardwell et al. 1978). Applied research aimed at facilitating breeding of domestic varieties for paddy cultivation has determined various mechanical, sonic and thermal treatments to break dormancy. Results of these and other investigations have shown that the dormant period can be extensive, and assists in maintaining seed viability. Such a mechanism is an essential adaptation to climatic seasonality, as well as to periodic loss of the current year's growth prior to maturation (seed crop failure). Simpson concluded that, unlike most terrestrial plants, wild rice seed undergoes gradual loss of dormancy under the low oxygen conditions which may exist in bottom sediments in winter.

Germination takes place at between 4-6°C, and may be enhanced by temperature fluctuations of the type which would occur during spring turnover in lakes or the commencement of spring flood in streams. Upon germination the seedling may yet be exposed to relatively low O₂ conditions. Wetzel (1975) states that the young foliage of aquatic emergents must be capable of respiring anaerobically. Yamashaki (1984) concluded that O₂ supply to the roots limited the depth at which the Asian perennial Zizania latifolia could survive. Svare (1960) determined that concentrations of less than 1 ppm O₂ inhibited wild rice root growth in the seedling stage. The circulation of dissolved O₂ by currents and the oxygenation of sediments via aforementioned mechanisms of sediment disturbance are of importance in ameliorating this situation.

Figure 1.3 depicts wild rice in flower. Growth and development of the plant is well documented (Rogosin 1951; Steeves 1952; Weir and Dale 1960, Oelke et al. 1982). The first segment of the typical life history is the vegetative growth phase which is initiated with the submersed stage. Two or three slender leaves are produced; these eventually die off following commencement of the floating leaf stage. One or two ribbon-like leaves lie on the surface, their upper surfaces textured to shed water and remain exposed to the

Figure 1.3. Morphology of wild rice in flower (adapted from Oelke et al. 1982; Sask. Agric. 1983).

air. At this point the plant has gained access to the increased light, O_2 and CO_2 available above the water. The floating leaves also enable O_2 diffusion toward the roots by means of large intrafoliar lacunae.

Within a week or two of the appearance of the floating leaves production of 3 or 4 long, narrow aerial leaves occurs and stem elongation takes place. The Interior variety is described at maturity as 0.9 to 3.0 m tall, with 10 to 30 mm wide leaves, the Northern variety as 0.7 to 1.5 m tall, with leaves 4 to 10 mm wide (Steeves 1952; Dore 1969). From 3 to 5 nodes are produced; the amount of internodal stem elongation is also affected by water depth. Minimum length is dictated in the deepest sites by the need for stems to emerge. As a result, plants of a single variety, in the same habitat, may vary substantially in overall height. The hollow center of the 5 to 10 mm diameter, lignified stem consists of large, regularly-spaced, membrane-divided lacunae which permit diffusion of gases. By this stage the plant is normally well anchored by a mass of short fibrous roots, with prop roots often arising from higher nodes. Root hairs are absent. As many as 50 adventitious stems called tillers can arise, either from the root crown or from lower stem nodes on the plant, in the last vegetative stage.

The reproductive growth phase overlaps the vegetative phase but is considered to begin shortly after the initiation of tillers. Weir and Dale (1960) noted that the conversion from a vegetative to a floral apex occurs as the aerial leaves emerge above the water surface, although the stem continues growth until just prior to seed maturity. Wild rice forms a monoecious, gynaeandrous panicle. The female florets are borne above the male florets and are thus deployed earlier, virtually assuring cross-pollination, with wind as the chief agent. The propensity of the species to produce intervarietal hybrids, and to exhibit considerable phenotypic heterogeneity, may be explained in part by this assured cross-pollination. Floret production differs between varieties. Lower pistillate branches of the Northern variety tend to have 6 or fewer florets, while on the panicles of the Interior variety the lower pistillate branches number 10 to 30 (Steeves 1952; Dore 1969). The former usually has less than 40 pistillate florets in total, the latter can have in excess of 200 on a single stem.

Maturation occurs progressively downward from the panicle tip over a period of 10 to 14 days. A 1 to 2 cm long seed is produced, enclosed in a palea and an awned (2 cm) lemma. Lee (1979) noted a south to north gradient of increasing seed length that was attributed to the

predominance of the Northern variety at higher latitudes. Ripe seeds in natural stands dislodge or "shatter" easily from the panicle due to wind or other jostling. Unlike most other aquatic macrophytes, whose seeds tend to remain buoyant for dispersal, the heavy wild rice seeds sink rapidly, awn trailing, to embed in the sediments near the parent plant (Dore 1969). There they lie dormant for at least one, and possibly several, winters. Viability is quickly reduced by seed drying, although freezing of the sediment will not destroy all of the seed (Fyles 1920). Following maturation the parent plant begins to die off and much of the stand's stems may be broken, floating or submerged by the time ice returns (Rossman 1973). Nutrients are rapidly leached from dead macrophyte tissue (Wetzel 1975), although Sain (1984) found that the net annual accumulation rate of wild rice straw can be on the order of 6 to 28 % (residual dry weight).

1.4 Environmental Factors Affecting Growth

Climate, water depth, light and substrate conditions constitute the major physical variables governing wild rice growth performance and distribution. The rate of development varies in response to a number of factors resulting in annual, intrasite and intervarietal differences in germination, emergence, flowering and maturation dates. With

regard to climate, the main considerations are length and character of the growing season. In broad terms the effective length of the growing season is defined by the frost free period. However, wild rice is essentially "sheltered" from early summer frosts while submerged, but may be severely damaged or killed entirely by late summer frost (Brooks 1966).

Monitoring in Minnesota paddies shows that between 85 and 130 days, with a mean of about 110 days, are required to complete the life cycle (Oelke et al. 1982; Grava et al. 1977-82). Aerial leaf emergence and flowering occur at approximately 30-35% and 65-75% respectively of the period from germination to seed maturity. Significant reproductive failure is also related to occurrence of either very hot, dry weather, or excessive rain, during pollination (Moyle 1944). This is attributed to withering of the stigmatic hairs, and to reduced pollen drift, respectively. Since the seed is able to withstand freezing under wet conditions (freezing of lake to bottom), winter temperatures are not considered a major problem (Fyles 1920).

Climate is closely related to water level stability through variability of precipitation (affecting water depth, peak runoff timing), and influences water movement and

circulation via wind (wave) action. Established wild rice stands can withstand sluggish to moderately strong currents, but strong or persistent wave action can uproot the plant, especially in the vulnerable floating leaf stage. This restricts the plant to sheltered bays and inlets on larger lakes. At the same time the optimum water regime during any growing season is a stable or gradually receding one, but an annual recurrence of fluctuation is also desirable since prolonged stable water levels can facilitate invasion of perennial emergents. Water level increases on the order of 15 cm during the floating leaf stage are capable of reducing vigor, while a sudden rise of about 30 cm will "drown" the plants at that stage by impaired access to O_2 (Rosogin 1951).

High levels of light are required by wild rice. Strong water colour, high turbidity, and even the shading effect of wooded shorelines can account for absence of the species. Lee and Stewart (1984) correlated growth with measured light extinction coefficients and concluded that habitat potential could be assessed, in part, by light attenuation rates in a particular water body.

Wild rice appears to tolerate a broad range of substrate textures and sediment depths. Stands have been reported in sand, alluvial silts, and in deep, soft organic mucks or

oozes of 45 to 60 cm depth. Optimal conditions seem to be about 15 to 45 cm of loose silts or clays and organic material to permit full root growth for anchorage (Rogosin 1951). However, Lee and Stewart (1984) also noted that a top layer of very loose flocculent material did not provide suitable substrate.

Chemical aspects of the habitat of aquatic emergents are complex and incompletely understood. Wetzel (1975) points out that two views are held in limnology regarding nutrition and ionic absorption in aquatic macrophytes: first, that nutrients are obtained directly by absorption into submersed foliage; and secondly, that the rooting systems, more than merely mechanisms for anchorage, function as the main sites for uptake of nutrients. Evidence for both views exists, and it may be expected that each is important, though not necessarily to the same extent throughout the life cycle. Pearsall (1920) concluded that for rooted macrophytes sediment chemistry was more crucial in determining distribution than was water chemistry. Moyle (1945) however, felt the converse was true, but conceded that within the range of tolerance (of water chemistry), type and nature of the substrate was responsible for local variations in plant distribution. Seddon (1972) later agreed following a study which, like that of Moyle, correlated floristic lists for

various lakes with selected water chemistry data.

Wild rice may be generally described as inhabiting primarily mesotrophic lakes of low salinity and near-neutral to somewhat basic pH. Both Rogosin (1951) and Lee (1979) agreed that the plant is found in both Moyle's (1945) hard water and soft water lakes. The former, with pH of 8.0-8.8, have alkalinity and TDS values in the ranges of 40-200 and 150-300 mg l⁻¹ respectively. The latter, with a pH range of 6.8 to 7.4, tend to have total alkalinity values less than 40 mg l⁻¹ and total dissolved solids (TDS) less than 80 mg l⁻¹. Moyle and Lee also considered Northern wild rice to be more abundant in the lower alkalinity and sulphate conditions of the soft water lake.

Lee (1979) stated growth occurred in moderately acid sediments, while Peden (1982) confirmed sediment pH to be in the range of 5.4 to 6.8. At any site conditions of both sediment and water chemistry will vary over the growing season (Wetzel 1975). Nevertheless, several workers (Lee; Peden; Archibold and Welch 1983; Atkins 1984; Garrod 1984) have investigated the relationship between wild rice growth performance and sediment nutrients. Lee attempted to relate both water and sediment chemistry with wild rice phenology and elemental concentrations in tissue, but found generally

poor correlations. This may be explained by the concept of luxury consumption; if a plant occurs at a particular location, the concentration of an element in tissue can be excess of the minimum required for growth and development, and may be independent of biomass beyond the critical minimum for survival (Wetzel). Both Peden and Garrod found positive correlations of performance with various nutrients, particularly phosphorus, while Garrod concluded that at many sites sediment nutrient levels may be too low to sustain wild rice.

The major biological aspects include interspecific and intraspecific competition, grazing, and depredation by pathogens. As an annual with a high light requirement wild rice is a very poor competitor, and is readily excluded from the littoral zone by perennial emergents (McDonald 1955; Dore 1969; Atkins 1984). Moyle (1944) described the species association in wild rice stands as one characterized by annuals which grow from either seed or overwintering buds. Submergents such as Utricularia spp. (bladderworts), Ceratophyllum demersum L. (coontail) and Potamogeton spp. (pondweeds) are typical, as are the floating-leaved submergents like Nuphar spp. (pond lilies) and Nymphaea spp. (water-lilies), as well as the small free-floating plants such as Lemna trisulca L. and Spirodela polyrrhiza (L.)

Schleid (duckweeds). Dore (1969) pointed out that the large floating leaves of pond lilies may reduce competition by extensive shading of the bottom, whereas wild rice normally is emerged before the pond lily leaves expand. Neilson (1964) proposed the presence of pond lilies in moderate to light densities as an indicator of suitable habitat. In locations with well established perennial emergent communities wild rice is relegated to the middle littoral zone. Intraspecific competition is evident in dense stands, resulting in reduced vigour; 3 to 6 tillers per plant are considered average for optimum densities of approximately 45 plants m^{-2} (Oelke et al. 1982). Under crowded conditions the phenotypic differences between Northern and Interior varieties are significantly diminished (Dore 1969).

Wild rice is relished as a food source by wildlife to the extent that it was often introduced to enhance marsh habitat (Stoddard 1960). Deer, moose, muskrats, carp, crayfish, waterfowl and various marsh birds consume the plant. The latter two feed mainly upon mature seeds, although waterfowl will also eat the floating and newly-emerging aerial leaves. Impact on established stands is generally not significant, but muskrat and carp have occasionally been blamed for destruction of whole wild rice beds (Steeves 1952). Insect depredation is considered more serious.

Observations have been made of various aphids, leafminers, leafhoppers, thrips, and water weevils (Peterson et al. 1981; Oelke et al. 1982). The most damaging pests are considered to be the larvae of two noctuid moths: Apamea apamiformis Guenee (riceworm), and Chilo pladiadellus Zincken (rice stalk borer). The former, which hatches in the florets and consumes the ovary, has been blamed for periodic devastation of stands (Melvin 1966; Steeves 1952). The latter feeds on foliage before weakening the stems by living and feeding in the stalk lacunae. The most significant fungal pathogens in natural stands in Canada are reported to be Claviceps zizaniae Fyles (an ergot) on the seeds, and Entyloma lineatum (Cke.) Davis (a stem smut), though Dore (1969) contends that neither is severely destructive nor widespread.

1.5 Considerations with Respect to Distribution

Little is known of the paleoecology of wild rice. It seems logical to presume that northward range expansion could have been facilitated by retreat of the Wisconsin Ice Sheet circa 12,000 years B.P. McAndrew's (1969) study of pollen stratigraphy at Rice Lake in central Minnesota found wild rice present at around 4000 years B.P., with a rapid proliferation circa 2000 years B.P. The increase was postulated as having been a response to climatic change,

relative stabilization of water level and continued sediment aggradation. In a later detailed study of sediment lithology Birks (1976) dated the appearance of wild rice to about 10,550 years B.P. at Wolf Creek in central Minnesota. Here, as in the Rice Lake study, the sediment changed from marl to softer detrital copropel which was interpreted as reflective of a transition to lower carbonate levels and conductivity, possibly related to an in-filling hydrosere. The reconstructed floral assemblages suggest these post-glacial lakes were not eutrophic. Seddon (1972) felt that for macrophytes restriction toward eutrophic conditions indicates an obligate relationship due to physiological demands. Conversely, species from dystrophic and oligotrophic waters can have broad tolerances and are thought to be excluded from high trophic status sites primarily by competition.

A northern limit, determined by the requirement for sufficient heat income and frost-free period, must logically exist but is not established in the literature. Intolerance of salts, particularly sulphates, is likely to be one factor excluding wild rice from the more arid central plains of North America where annual moisture deficits contribute to higher salinity. In addition, water bodies on the central plains are often eutrophic, supporting heavy growths of aquatic macrophytes in which wild rice would be unable to

compete. The Northern and Interior varieties are also reported to grow poorly in the warmth and short daylengths of southern locations (Oelke et al. 1982; Winchell and Dahl 1984).

Dore (1969) discussed the generally patchy distribution of wild rice within its overall range, speculating that this was the result of two factors. First, as an annual, it is best adapted to recurrence of sufficient disturbance to reduce competition. Habitats which meet this requirement simultaneously with the other environmental requirements of the species may not be widely available in natural terrain. Secondly, the plant has certain characteristics which inhibit natural dispersal. The heavy seed sinks immediately and resists transport by currents. Rapid loss of viability upon drying, and high digestibility of the seed, preclude easy dispersal via ingestion by fauna.

Translocation of wild rice is thought to have been intentionally or inadvertently caused by the native Indian cultures which had relied upon its harvest for about 1000 years (McAndrew 1969). Dore (1969) concluded this is evidence that the potential range is very great. His assertion that the potential range probably encompasses "the temperate and tropical portions of all continents, wherever suitable

conditions occur" may be an exaggeration, particularly with respect to the varieties of Zizania palustris. Commercial interest has resulted in numerous stands being successfully established at widely separated locations in the last 100, and especially the last 50, years. Saskatchewan is a prime example of the latter period, as described in Chapter 2.

Chapter 2

WILD RICE IN SASKATCHEWAN

2.1 Development and Distribution

While there is no specific information, it is known that the introduction of wild rice into northern Saskatchewan took place during the mid 1930's (Neilson 1964). Seeding was initially carried out by government resource personnel, ostensibly to provide food for muskrat and waterfowl, thereby enhancing trapping and hunting opportunities for northern residents. The plant's presence in Saskatchewan prior to that time remains a remote possibility but may never be known. Leighton (1982) suggests that the wild rice use was not a part of the ethnobotany of the Cree Indians of this region. Inadvertent introduction by early European fur traders and explorers would have been precluded by the fact that the seed is no longer viable once processed and dried for consumption.

Four established stands -- Limestone Lake, Potato Lake, Nemeiben Lake and Pine Branch River -- were known to exist by the early 1960's when an interest arose in the commercial potential of the crop. Much of the effort to extend the wild rice distribution during this period is attributed to the

late J. D. Neilson, working for the Saskatchewan Department of Agriculture. Commercial harvesting began in 1965 and by 1968 reached approximately 14,000 kg (Orcajada 1982).

Government involvement in the expansion of the wild rice industry began in earnest in 1978 with extension and demonstration programs, as well as the provision of seed grants to northern residents. Regulations were created stipulating that permittees would be long time residents of the Northern Administration District and limited to 400 ha total permit area each. High wholesale prices, generally in excess of \$7.00 per kilogram (processed), spurred enthusiasm (Winchell and Dahl 1984). Thus, conditions were not only favourable for increasing production, but also for rapid and significant dispersal of wild rice stands throughout northern Saskatchewan.

By 1984 the Saskatchewan harvest had jumped dramatically, giving it the largest production in Canada at approximately 490 000 kg (Figure 2.1). The increase was due to a combination of new stand establishment and greater use of airboats to harvest the existing crop more effectively. These two factors helped to offset, but not eliminate, any natural fluctuations in production caused by variations in weather or water levels. An example of the importance of the

Figure 2.1. Wild rice production in Canada since 1970

weather factor occurred in 1982 when 50 to 100% damage was done to many stands by early frost.

Owing to the rates at which new permits were being approved, and non-renewed permits cancelled, it became very difficult to monitor the situation with respect to distribution. The number of permit holders remained well ahead of the number of successful commercial producers, those being estimated at 700 and 80 respectively in 1983 (Winchell and Dahl 1984). A search of provincial government files revealed concentrations of both permits (Figure 2.2) and established stands of wild rice (Figure 2.3) in a zone south of the Churchill River.

2.2 Previous Research

The occurrence of wild rice in this province was not widely known prior to the mid 1960's. Its presence here is not mentioned in a general overview of the topic by Steeves (1952) and it is not listed in a flora by Fraser and Russell (1954). The oldest Saskatchewan specimens in the W. P. Fraser Herbarium, University of Saskatchewan, are dated 1964. Since initial studies were primarily laboratory-oriented, there was a need for methods of ensuring seed dormancy could be broken, in order to germinate specimens (Simpson 1966; Vicario and

Halstead 1967; Halstead and Vicario 1969). Studies were done on the growth of wild rice in prairie soils (Weber 1967; Weber and Simpson 1967), on the effects of sulphates, lime and added nutrients on growth performance, as well as on the effects of using herbicides to reduce competition (Vicario and Halstead 1967 and 1968; Halstead 1969).

No laboratory studies were conducted in Saskatchewan in the 1970's. With the establishment of more wild rice stands however, the opportunity for field studies improved. In 1975 a comparative survey of waterfowl population densities suggested that wild rice stands presented attractive habitat for various species of ducks (Peden 1977). The same year samples of lake sediment and wild rice plants were collected from 17 stands centered in the La Ronge area. These were used to investigate the relationship between substrate chemistry and plant growth (Peden 1982). Similar ecological research was initiated in 1982 with monitoring of habitat conditions and plant growth at 5 stands near La Ronge (Archibold and Weichel 1983). Thus, while the more recent research provided some understanding of actual habitat conditions in wild rice stands, there remained a need for a regionally-extensive study of habitat potential.

Chapter 3

PROCEDURES AND METHODS

3.1 Wild Rice Habitat and Growth Performance

Data were obtained both directly in the field from existing stands during late August to early September, 1983, as well as from further laboratory work on collected samples. An effort was made to have as wide a distribution as possible, subject to time and accessibility constraints. Most wild rice is currently grown south of 56° north latitude and within this portion sites were chosen to provide representation from the main habitat types.

The Precambrian Shield constitutes the major feature of geological and physiographic importance in northern Saskatchewan. It is distinguished as a glacially-scoured area of ancient, mainly intrusive and metamorphosed bedrocks; granites and gneisses are predominant although there is also an extensive sandstone basin. Bedrock exposures are widespread, while other portions have only a thin mantle of drift. These characteristics mean that surficial geology on the Shield, with its hard, largely impervious rocks, dramatically affects dissolved mineral levels in groundwater

and runoff. In the southern part of the region the Precambrian basement is overlain by younger sedimentary rocks more continuously covered by drift. Waters in this latter area reflect the difference in surficial geology from that of the Shield. This distinction is thus relevant in terms of the sampling distribution used.

Thirty-six sites were established, 12 situated in each of the eastern, central and western areas of the region (Figure 3.1). Both lentic and lotic habitats were included and sampling was carried out both north and south of the margin of Precambrian Shield (Figure 3.2). Measurements and collections were made at each of 9 stations per site (324 stations total). An equitable distribution was hampered by the concentration of established stands south of that margin (off the Shield) in waters on drift-covered sedimentary bedrocks (Table 3.1).

Fieldwork was confined to the period of seed maturation to minimize seasonal fluctuations in environment and to coincide with maximum live weight of the wild rice plants. Table 3.2 lists the variables measured while procedural details are outlined below. Station spacing (approximately 10 to 50 m) and transect spacing (approximately 20 to 75 m) was varied with the size of the wild rice stand to ensure

Figure 3.1. Framework used to differentiate habitats within the current main wild rice growing areas.

..... SOUTHERN LIMIT OF SHIELD

Figure 3.2. Location of 36 sites at which sampling stations were established.

TABLE 3.1. NUMBER OF STATIONS SAMPLED BY HABITAT TYPE

<u>SAMPLING AREA</u>							
	<u>EAST</u>		<u>CENTRAL</u>		<u>WEST</u>		
	<u>LAKE</u>	<u>STREAM</u>	<u>LAKE</u>	<u>STREAM</u>	<u>LAKE</u>	<u>STREAM</u>	
On-Shield	36	27	45	--	--	--	Subtotal 108
Off-Shield	18	27	45	18	45	63	216
Area Totals	108		108		108		[N=324]

adequate coverage within the overall perimeter (Figure 3.3). A total of 1820 mature wild rice stems (mean of approximately 50 per site) was collected for morphological and productivity determinations.

3.1.1 Habitat Variables

A. Water: all measurements were conducted at sampling stations, and at various times between 0800 and 1800 hrs.

i) depth - was recorded as height of water level above apparent bottom. A graduated, 4 cm x 4 cm pole was submerged adjacent to plant quadrats. In many locations the uppermost sediments were very loose, flocculent debris; values therefore represent the distance to surface from top of the wild rice rooting zone.

ii) pH - was measured at surface with a Metrohm Herisau model E488 pH meter.

iii) conductivity - was measured midway from surface to bottom with a YSI model 33 S-C-T meter.

iv) temperature - was recorded at mid-depth with both meters as in iii) and v).

v) dissolved oxygen - was measured at mid-depth with a YSI model 51B meter.

vi) total alkalinity - was obtained from titrations on

TABLE 3.2. VARIABLES MEASURED AT SAMPLING STATIONS

Water	Sediment	Wild Rice
-depth	-depth	-mature stem density
-pH	-pH	-plant & seed weight ¹
-conductivity	-wild rice thatch	-leaf, flower & stem sizes
-temperature	-macronutrients ²	-% tiller stems
-dissolved O ₂	(NH ₄ ⁺ & NO ₃ ⁻ nitrogens, inorganic phosphorus, SO ₄ -sulphur	-female florets
-total alkalinity		

¹plant measurements obtained for samples taken from sampling stations, except seed weights based on composite samples for entire sites

²analysis was done on 3-station composite samples from inshore, midway and lakeward (lake sites) or bank, midchannel and opposite bank (stream sites) station combinations.

Figure 3.3. Typical sampling station placement.

near-surface samples using a Hach Chemical water testing kit.

B. Sediment: depth, pH and thatch values are from on-station measurements. A sample of sediment from the upper 50-60 cm was obtained at each station. Samples were air dried for storage and transport and later analyzed for macronutrients at the Saskatchewan Soil Testing Laboratory, University of Saskatchewan, Saskatoon. Results are based on analysis of three-station composite samples for transects oriented parallel to shore: inshore, midway and offshore at lake sites; near-bank, mid-channel and opposite near-bank at stream sites.

- i) depth - is an estimation of probable thickness of the rooting zone. The pole described in A.i above was inserted into the sediments, with consistent effort, until solid material (sand, gravel, rock) was encountered. Depths in excess of 100 cm (thick peats or organic mucks) were recorded as 101 cm.
- ii) pH - was measured on sediment during collection using meter in A.ii above.
- iii) thatch - refers to a visual assessment of the accumulation of undecomposed wild rice straw on sediment surface at each station. The mass of straw was sampled with a paddle blade swept along bottom for 50 cm and up

to water surface. Values are defined as: 0 = nil to sparse, 1 = very light to light, 2 = light to moderate, 3 = moderate, 4 = moderate to heavy, 5 = heavy, 6 = very heavy.

iv) macronutrients - were determined for composite samples using the following extractants: 2N KCl (for $\text{NH}_4\text{-N}$); 0.001 M CaCl_2 (for $\text{NO}_3\text{-N}$ and $\text{SO}_4\text{-S}$); 0.5N NaHCO_3 (for inorganic P and K). The analytical procedures are designed for discerning plant nutrient limitations in terrestrial soils and therefore resulted in $\text{SO}_4\text{-S}$ values for all but 2 samples being recorded simply as greater than 20 mg l^{-1} .

3.1.2 Wild Rice Variables

At each sampling station the density of mature aerial stems was counted in a floating 0.25 m^2 quadrat. Sufficient whole plants (including roots) were collected to ensure a minimum of 25% of stems were taken from within the quadrat. (The plants are readily pulled up with negligible loss of root mass.) In sparse stands 50% of stems were taken if density was 10 or less; 100% were taken when density was 4 or less. Samples were air dried prior to morphological measurements, while weight determinations were made after oven drying at 80°C for 24 hours.

- A. Stem Density: in all but very sparse stands a 0.25 m^2 quadrat was used. At some stations a 1.0 m^2 or 2 m^2 quadrat was needed. Stations were distributed in a regular fashion (consistent spacing adjusted for size of stand); densities of 0 were possible if stations fell in large openings within the overall stand perimeter.
- B. Weights: recorded as station means for oven dry samples, except in the case of seeds, which are for composites samples collected at random throughout the stand.
- i) weight per stem - found from weight of plant (roots, stems, leaves, flowers) divided by the number of mature stems.
 - ii) seed weight - per seed, is based on mean of 3 replicates of 100 seeds enclosed in their lemmas and paleas.
 - iii) biomass - is an estimate of total weight, seeds included, per hectare. For each station the value is derived from:
$$[(\text{density})(\text{stem wt.}) + ((\# \text{ of florets})(\text{density}) \text{ seed wt.})]$$
Seed weight was estimated from mean number of female florets per panicle assuming 100% pollination and maturation.
 - iv) maximum yield - again assumes all florets produce mature seed. It estimates the theoretical green (40% moisture) crop weight producers would obtain if all seeds could be

harvested.

v) stem unit weight - results from dividing weight per stem value by the mean total stem length in meters. This provides an indication of relative robustness of the vegetative component as a function of stem thickness and amount of foliage. It compensates for length-related differences in weight per stem.

C. Plant morphology: measurements were obtained from individual aerial stems (air dry). Values are station means.

i) total stem length - was measured from the base of the stem to the tip of the flower head.

ii) internodes per stem - is the number of internodal stem sections between root mass and the base of the male portion of the flower head.

iii) total flower length - is the entire length of the inflorescence from the base of the staminate portion to tip of the pistillate portion.

iv) female flower length - is the length from the base of the pistillate portion only.

- v) female florets per head - was obtained by counting the pedicels to which the florets were attached prior to seed maturity.
- vi) floret density - number of pistillate florets divided by the length (cm) of the pistillate portion of the flower head. This compensates for length as in B.v above.
- vii) aerial leaf width - was measured on the sheath, midway from base (at stem node) to ligule, due to the breakage of leaf blades in transport of dry samples. Values are means for the two uppermost aerial leaves.
- viii) percent tiller stems - is the proportion of all stems in the quadrat which arose as tillers, either from the plants' roots, or from nodes of other stems. (For each multiple-stem specimen all stems but one are tillers.)
- D. Productivity Index: This is a unitless measure incorporating vegetative and seed production. Values were derived as the product [stem unit weight X female florets per head]. Wild rice of identical stem lengths may therefore differ in index value; the lowest values describe spindly, weak-stemmed plants with very few potential seeds, while the highest indices indicate stocky, leafy plants capable of producing large numbers of seeds on each stem.

3.2 Regional Climate

3.2.1 Background

Significant variations in elements of climate are not unusual over areas the size of northern Saskatchewan; the region covers approximately 297,000 km². A generally southwest to northeast gradient is recognized, along which there is a transition toward more severe subarctic conditions (Chakravarti 1969; Wheaton 1979). Precipitation is important through effects on water levels, but northern hydrology is exceedingly complex and scarcely monitored. The focus in this study has been on temperature and light.

Important variables of the thermal regime are length of the growing season (frost-free period) and the temperature conditions during that time (Nuttonson 1957; Lowry 1968). Within the constraints of above-freezing temperatures there must also be a sufficient period of time during which there is enough light (daylength) and warmth to meet the metabolic requirements of the species. In the case of wild rice late spring or early summer frosts are less of a constraint than for terrestrial plants because initial growth is submerged. This introduces problems in applying frost-free period length directly. Seed maturation is spread over a 10-14 day period

during late August and early September at a time when the probability of frost is increasing daily. In 1982 heavy late August frost damage was widespread in the study region and at many locations caused virtually complete crop losses.

3.2.2 Methods

The approach employed was restricted by a lack of phenological data and the relatively sparse amount of climatic data available for the region. To compensate for the former it was necessary to assume that the initiation of harvest would be a logical indication of when wild rice crops reached maturity. Such information was obtained from La Ronge Industries Ltd. (for 1967-1983) enabling temporal distribution of maturity date to be estimated for the central area of the major production zone (south of the Churchill River). Monthly mean temperatures were obtained for 10 stations in the study region as well as 9 peripheral locations (Environment Canada 1982). This provided a basis for estimates of heat and heat/light (photothermal) accumulation over the growing season.

Heat units were calculated as growing degree-days (GDD) above base 5°C using:

$$[GDD = (\text{mean monthly temp.} - 5^{\circ}) \times \text{no. of days}]$$

summed for May to September inclusive. Photothermal units (PTU) incorporate day lengths at a station's latitude using:

[PTU = monthly GDD X mean day hrs.]

summed for May to September inclusive. Wheaton's analysis of the climatic environment of northern Saskatchewan afforded an opportunity for comparison of values for GDD and frost-free period. Finally, a data set of minimum daily temperatures for Saskatchewan stations (complete record years only) was available at the University of Saskatchewan (Le Boutillier and Waylen 1984). This served as a source from which to compute frost-free period, fall frost dates and minimum GDD and PTU values.

3.3 Overview of Intraregional Potential

The size of the study region, the amount and detail of pertinent available information, and the stated objectives (page 4) necessitated the use of an Ecological Land Classification (ELC) approach. The ELC methodology is an integrative one which allows use of a number of interrelated environmental criteria in mapping areal units at various scales (Wiken et al 1982; Bradley et al 1982). A hierarchy of levels of generalization is involved and the approach facilitates classification that may simultaneously include subdividing large areas and aggregating smaller ones. The

emphasis has been on use of climate, physiography, surficial geology and geomorphology as classification criteria. No attempt was made to utilize other aspects, terrestrial flora and fauna for example, less directly connected to conditions in littoral habitats.

Physiographic divisions for the province were mapped by Acton et al. (1960), while Pearson and Whitaker (1972) mapped bedrock geology. Liaw and Atton (1981) synthesized limnological data from over 600 Saskatchewan waterbodies, including 158 located on the Precambrian Shield. This provided an overview of water chemistry variables. Koshinsky (1970) examined Shield lakes in terms of aspects of morphometry commonly used in evaluating potential aquatic productivity. In addition to consultation of the literature extensive use was made of topographic maps (1:500,000 and 1:250,000) in concert with satellite imagery (Landsat: band 6 B/W prints and false colour transparencies of bands 4,5,7; both at 1:500,000).

The mapping of subregional areas was initially carried out on a 1:760,000 base map, placing the operative scale of the classification at the ecoregion/ecodistrict levels of generalization. (The final map is depicted at a scale of 1:4,000,000.) The process of implementing the ELC method

involved superimposing, on the base map, a series boundaries for relevant criteria. As each criterion was added the spatial extent of the districts emerged. For example, within portions of the region that are homogenous with respect to surficial geology, it was possible to distinguish areas of differing densities of lakes of in a certain size range. The overall process entailed a significant amount of subjective judgement in final district boundary placement.

Chapter 4

RESULTS

4.1 Wild Rice Habitat and Growth Performance

4.1.1 Variations in Environmental Factors and Wild Rice Growth

The majority of the variables are based on measurements taken at 324 stations. Sediment macronutrients and seed weights are based on composite samples for transects and sites respectively. The data provide a regional cross-section; habitat conditions and plant performance are summarized in Tables 4.1 and 4.2 respectively. The distributions of values across their ranges are shown and indicate the extent to which it is meaningful to characterize "typical" conditions. For a number of these variables, especially those listed in Table 4.2, relatively broad ranges and high standard deviations demonstrate the difficulties inherent in attempting to define a typical situation.

Several incidental observations provided values outside the ranges given in Tables 4.1 and 4.3. For example, at site 28 a number of unusually large plants were encountered for

TABLE 4.1. DISTRIBUTION OF WATER AND SEDIMENT
VARIABLES FOR ALL SAMPLING STATIONS

<u>VARIABLE</u>	<u>MEAN</u>	<u>ST.DEV.</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>MEDIAN</u>
Water					
depth (cm)	92.9	35.8	19.0	191.0	100.0
pH	7.67	0.62	6.40	9.40	7.50
conductivity ($\mu\text{S cm}^{-1}$)	144.8	66.6	42.0	280.0	143.5
temperature ($^{\circ}\text{C}$)	19.8	2.3	13.5	25.0	20.0
dissolved O_2 (mg l^{-1})	7.3	2.8	1.4	14.0	7.4
total alkalinity ($\text{mg l}^{-1} \text{CaCO}_3$)	87.8	41.7	15.0	180.0	92.5
Sediment					
depth ¹ (cm)	66.2	26.4	10.0	101.0	62.0
pH	6.41	0.28	5.63	7.46	6.44
thatch ²	0.7	1.4	0.0	6.0	0.0
$\text{NH}_4^{+}\text{-N}$ (mg l^{-1})	53.9	32.1	10.0	165.0	45.0
$\text{NO}_3^{-}\text{-N}$ (mg l^{-1})	4.4	6.3	0.1	26.5	1.8
P (mg l^{-1})	5.8	7.1	1.0	46.0	4.0
K (mg l^{-1})	90.7	39.1	35.0	215.0	80.0
$\text{SO}_4^{2-}\text{-S}$ (mg l^{-1})	-	-	15.0	-	-

¹ At 24% of stations firm substrate was an undetermined amount greater than 100 cm and was recorded as 101 cm. For stations with depth < 100 cm the mean was 54.7 cm.

² Amount of thatch cover over sediment was assigned values between 0 (nil) and 6 (very heavy).

³ All $\text{SO}_4^{2-}\text{-S}$ values except 2 were greater than 20 mg l^{-1} and actual values are not known; one value of 15.0 and another of 16.0 were determined.

**TABLE 4.2. DISTRIBUTION OF WILD RICE
VARIABLES FOR ALL SAMPLING STATIONS**

<u>VARIABLE</u>	<u>MEAN</u>	<u>ST.DEV.</u>	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>MEDIAN</u>
stem density (m ⁻²)	62.2	59.8	0.3	372.0	52.0
weight per stem ¹ (g, dry)	2.7	1.6	0.2	8.1	2.3
seed weight ² (mg)	44.0	9.0	18.0	60.0	45.0
biomass (kg ha ⁻¹)	2,932.7	2,800.0	7.3	16,880.7	2,206.7
max. yield (kg ha ⁻¹)	1,647.4	1,838.6	2.7	12,037.9	1,128.5
stem unit wt. (g)	1.9	1.2	0.3	9.9	1.6
total stem length (cm)	147.0	32.2	57.0	230.3	149.2
internodes per stem	3.9	0.4	2.5	5.0	3.9
total flower length (cm)	40.5	7.6	20.7	58.8	40.9
female flower length (cm)	20.1	5.0	9.3	39.4	19.5
female florets per head	36.8	22.7	6.0	153.4	30.6
floret density (cm ⁻¹)	1.8	0.9	0.4	5.7	1.5
leaf width (mm)	13.8	3.9	5.3	24.8	13.6
% tiller stems	35.9	31.1	0.0	93.8	33.3
productivity index ⁸	89.5	107.7	2.4	794.3	44.7

¹ Includes roots, stems, leaves and flowers; excludes seeds. All weights oven dry.

² Determined as mean (3 replicates of 100) from composite sample for site (9 sampling stations).

³ Based on entire plant including seed.

⁴ Estimate of potential maximum fresh weight (40% moisture) seed yield; assumes 100% pollination and seed maturity.

⁵ Number of female florets per cm of female flower length.

⁶ Width of aerial leaf sheath. Determined as mean from 2 uppermost leaves per stem.

⁷ Includes all tillers arising from root mass and stem nodes.

⁸ Derived from stem unit weight. x number of female florets.

which the productivity index value was approximately 1,236, considerably higher than the 794.3 maximum for plants collected at sampling stations. At sites 28, 29 and 30 mature plants were seen located on exposed mud as much as 15 cm above the late summer water level. Such observations are noteworthy because they emphasize the high degree of variability encountered. Furthermore, the latter observation, which suggests a minimum 15 cm seasonal decline in water level, underscores the limitations of a single-instance sampling at each site.

4.1.2 Intraregional Comparisons

The data may be examined from the perspective of whether habitat conditions and plant performance differed between the broad categories depicted in Figure 3.1. The stations can be grouped according to east, central and west sample areas, or on the basis of being in either the lake (lentic) or stream (lotic) habitat categories, or in terms of being located on or off the Precambrian Shield. Due to the orientation of the Precambrian Shield margin through the region (Figure 3.2), all stations in the western area are situated south of the margin and thus off the Shield. A t-test was used to test the significance of the difference between the various group means (SPSS 1983).

4.1.2.1 Sample Area Grouping

In the first instance a comparison is made between east, central and west sample areas within the region. Table 4.3 lists mean values for habitat and selected wild rice variables. Examination of the values suggests a number of cross-regional gradients, both in certain habitat conditions and in plant performance. Examples include water depth, pH, conductivity and alkalinity, as well as most of the measures of wild rice growth. Overall, the figures indicate decidedly greater productivity in the western area with an eastward decline. However, because the number of sampled locations within a particular type of habitat varied in response to availability and accessibility (Table 3.1), the differences in Table 4.3 must be considered in the context of the habitat groupings.

4.1.2.2 Lake/Stream Habitat Grouping

A second comparison is provided in Table 4.4 by grouping stations located in bays or along shores of lakes, and those in stream channels and mouths. Stream habitat had a mean depth of 80.9 cm, close to 21 cm shallower than the 101.6 cm depth for the lake habitat group. While temperature and

TABLE 4.3 MEAN VALUES FOR WATER, SEDIMENT
AND WILD RICE VARIABLES FOR EAST (n=108),
CENTRAL (n=108) AND WEST (n=108)
SAMPLING AREA GROUPS¹

Variables ¹	<u>EAST</u>	<u>CENTRAL</u>	<u>WEST</u>
Water:			
depth	111.3	108.5	58.9
pH	7.30	7.76	7.94
conductivity	102.0	142.8	189.5
temperature	18.3	21.1	19.9
dissolved O ₂	7.8	7.8	6.3
alkalinity	62.4	84.0	117.2
Sediment			
depth	62.5	68.9	67.1
pH	6.31	6.44	6.52
thatch	0.8	1.4	0.1
NH ₄ ⁺ -N	58.8	46.5	55.7
NO ₃ ⁻ -N	5.7	4.2	3.4
P _{inorg.}	3.2	9.0	5.6
K	120.3	84.7	66.6
Wild rice			
stem density	54.9	74.7	57.1
seed weight	39.0	50.0	44.0
biomass	1,859.4	2,763.3	3,906.2
max. yield	1,050.3	1,446.4	2,242.1
stem unit wt.	1.0	1.8	3.0
stem length	161.4	137.3	141.8
female florets	25.7	29.3	55.9
floret density	1.3	1.5	2.6
leaf width	11.9	12.6	16.9
% tillers	22.2	25.8	60.4
prod. index	31.2	64.7	175.4

¹see Tables 4.1, 4.2 for units of values

TABLE 4.4 MEAN VALUES FOR WATER,
SEDIMENT AND WILD RICE VARIABLES
FOR LAKE (n=189) AND
STREAM (n=135) HABITAT GROUPS¹

<u>Variables²</u>	<u>LAKE</u>	<u>STREAM</u>
Water:		
depth **	101.6	80.9
pH	7.67	7.66
conductivity *	138.2	154.0
temperature **	20.1	19.4
dissolved O ₂ **	8.0	6.3
alkalinity *	83.3	94.2
Sediment		
depth	66.7	65.5
pH *	6.46	6.37
thatch *	0.9	0.5
NH ₄ ⁺ -N *	50.4	58.6
NO ₃ ⁻ -N *	5.2	3.4
P inorg.	5.9	5.7
K **	82.2	102.1
Wild rice		
stem density *	55.0	72.2
seed weight **	46.0	41.0
biomass **	2,520.9	3,503.7
max. yield *	1,434.1	1,933.0
stem unit wt. **	1.7	2.1
stem length	146.4	148.0
female florets **	30.6	45.7
floret density **	1.5	2.1
leaf width **	12.8	15.6
% tillers **	31.1	42.7
prod. index **	65.1	124.9

¹differences between station groupings
 ** p < 0.01 * p < 0.05

²see Tables 4.1, 4.2 for units of values

dissolved oxygen were also slightly less for streams (19.4°C , 6.3 mg l^{-1}) than for lakes (20.1°C , 8.0 mg l^{-1}), there was no difference between the pH values of the two habitats, with both equivalent to the regional mean of 7.67. Conductivity was 138.2 uS cm^{-1} and alkalinity 83.3 mg l^{-1} in the lake group, indicating somewhat lower dissolved mineral levels compared with streams, where conductivity was 154.0 uS cm^{-1} and alkalinity 94.2 mg l^{-1} .

Generally, most sediment conditions were significantly though not drastically different between the two groups. Lake sites had only very slightly deeper and less acidic deposits of loose rooting zone sediments. In lakes ammonium nitrogen (50.4 mg l^{-1}) was somewhat lower than in streams (58.6 mg l^{-1}). The reverse was true for nitrate nitrogen levels (5.2 mg l^{-1} in lakes, 3.4 mg l^{-1} in streams). Phosphorus levels were nearly equal at 5.7 and 5.9 mg l^{-1} for streams and lakes respectively. Potassium content of lake sediments (82.2 mg l^{-1}) was about 20 mg l^{-1} lower than the value in streams (102.1 mg l^{-1}). The lake habitat also showed a tendency for greater amounts of wild rice thatch on the surface of the sediments, possibly as a result of less straw removal due to water movement than would be expected in stream sites.

Notable differences in plant morphology and productivity are also evident in the lake/stream comparison; however, this was not true of plant heights. Mean stem length was 146.4 cm in the lakes and 148.0 cm in the streams. In most respects the plants in the stream habitat were found to be more robust; vegetative production was greater while the potential was seen to produce more (albeit somewhat lighter) seeds. Examination of Table 4.4 will show the wild rice collected from streams had greater mean values for stem unit weight, number of female florets, floret density on the female flower and leaf width. As well, the stream sites had denser stands (72.2 stems m^{-2}) with a higher degree of tillering (42.7% of stems) than did the lake sites (55.9 stems m^{-2} , 31.1% tillers). At 124.9 the productivity index value of the stream habitat group is nearly twice the 65.1 value determined for the lake habitat group. The differences are further reflected in the biomass and maximum seed yield estimates since these are derived variables.

4.1.2.3 Shield Groupings

A third grouping of sampling stations allows comparison between locations north (on-Shield) and south (off-Shield) of the margin of the Precambrian Shield. Mean values in this instance are presented in Table 4.5. While water temperature,

dissolved oxygen and sediment depth were more similar here than in the lake/stream situation, more pronounced differences were noted in the remaining variables. Mean depth at off-Shield stations (79.2 cm) was about 41 cm less than at on-Shield locations (120.4 cm). The pH was significantly lower on the Shield (7.24) than off (7.88). Conductivity (73.1 uS cm^{-1} on-Shield; 180.7 uS cm^{-1} off-Shield) and alkalinity (41.9 mg l^{-1} on-Shield; 110.8 mg l^{-1} off-Shield) differences were particularly marked. Since these values are on the order of 2.5 times higher south of the Shield margin the effect of physiography on dissolved mineral content of water is readily apparent. Reduced nutrient status of on-Shield locations would also affect sediment chemistry and presumably diminish decomposition rates for organic detritus. Higher values were in fact found for the on-Shield group for wild rice thatch, nitrogen and potassium. However the mean phosphorous level on the Shield (2.9 mg l^{-1}) was less than half the off-Shield value (7.2 mg l^{-1}), suggesting the possibility of this important nutrient functioning as a limiting factor to some degree.

In terms of wild rice growth only mean stem density and seed weight differences were insignificant. Stem length was 141.6 cm for off-Shield plants and 157.1 cm for those on the Shield; some part of this may be due to greater on-Shield

TABLE 4.5 MEAN VALUES FOR WATER,
SEDIMENT AND WILD RICE VARIABLES
FOR ON-SHIELD (n=108) AND
OFF-SHIELD (n=216) HABITAT GROUPS¹

<u>Variables²</u>	<u>On-Shield</u>	<u>Off-Shield</u>
Water:		
depth **	120.4	79.2
pH **	7.24	7.88
conductivity **	73.1	180.7
temperature	19.7	19.8
dissolved O ₂	7.6	7.2
alkalinity **	41.9	110.8
Sediment		
depth	66.3	66.1
pH **	6.24	6.53
thatch **	1.3	0.4
NH ₄ ⁺ -N **	66.5	48.1
NO ₃ ⁻ -N *	32.6	5.0
P inorg. **	2.9	7.2
K **	107.7	82.9
Wild rice		
stem density	61.1	62.7
seed weight	44.0	44.0
biomass **	1,993.0	3,483.0
max. yield **	1,112.9	1,931.9
stem unit wt. **	1.1	2.3
stem length **	157.1	141.6
female florets **	22.1	44.7
floret density **	1.2	2.1
leaf width **	11.3	15.1
% tillers **	21.8	43.4
prod. index **	27.6	122.9

¹differences between station groupings
 ** p < 0.01 * p < 0.05

²see Tables 4.1, 4.2 for units of values

water depths. The remaining variables indicate that the former, though shorter, are stockier and exhibited significantly more vigor. On-Shield values for biomass, maximum seed yield, stem unit weight, number of female florets and percent tiller stems were approximately half those of the off-Shield group, with most of the additional floret production in the latter occurring as more densely-packed flower heads. The combined floret and vegetative differences resulted in a mean off-Shield productivity index value of 122.9, nearly 4.5 times greater than the on-Shield value of 27.6.

4.1.2.4 The Habitat Type Framework

The foregoing comparisons together suggest a hierarchy of habitat suitability in which all three locational distinctions are valid. The implication is that on-Shield lakes in the eastern area provide the least productive sites while at the other extreme off-Shield stream habitat in the western area may provide the best wild rice sites. Figures 4.1 and 4.2 depict mean values for several important plant and environmental variables within the sampled habitat types.

In terms of wild rice performance differences are evident between sampling areas for similar types of sites.

HABITAT TYPE KEY

	ON-SHIELD		OFF-SHIELD		
LAKE	1	5	3	6	8
STREAM	2		4	7	9

SAMPLE AREA

E	C	W
---	---	---

Figure 4.1. Mean values of selected variables in the habitat types.

HABITAT TYPE KEY

	ON-SHIELD		OFF-SHIELD		
LAKE	1	5	3	6	8
STREAM	2		4	7	9

SAMPLE AREA		
E	C	W

Figure 4.2. Mean values of selected variables in the habitat types. (cont.)

For example, the productivity index value increases westward for each of on-Shield lake, off-Shield lake and off-Shield stream habitats. (The fourth type, on-Shield stream, was only sampled in the eastern area.) There are also westward increases in leaf width, stem unit weight, and both the number of female florets and their ratio to flower length. This latter relationship suggests a gradational change in the number of florets per centimeter of panicle; irrespective of stem or flower length, the plants undergo a shift in floret density on the panicle.

The discrepancy in the central area, where the off-Shield lake sites have a higher index value than the off-Shield stream sites, is due to greater vegetative growth for the former, while the latter does in fact show the expected higher female floret density. Misclassification of habitat types may also be involved here since, in some cases, such as distinguishing lake from stream sites where stream channels entered small lake bays, required a subjective decision. Also in the central area, several sites were located in close proximity to the Precambrian Shield margin and were assigned to on-Shield or off-Shield groups in part on the basis of the predominant local drainage direction.

4.2 Regional Climate

Ideally climatic data should consist of long, complete records covering the same years for each of the stations being compared. Actual recorded values at a particular station will include variations due to localized effects such as elevation or proximity to large bodies of water. Despite the imperfections of the data (Table 4.6) they reflect the existence of a northeastward decline in the thermal regime.

Approximate positions of the 90, 100 and 110 frost-free days isolines are shown in Figure 4.3. As suggested earlier, this measure is not as directly important for wild rice because of the protection from spring frost afforded submerged plants in the early developmental stages. A more relevant measure might be obtained if it were possible to incorporate ice thaw and lake warming rates to derive a "starting point" for wild rice growth. On the other hand air and water temperatures are not unrelated. Thus in the broadest terms Figure 4.3 indicates that the northeastern portion, lying beyond the 90 day isoline, is of doubtful suitability for wild rice due to insufficient growing season length.

TABLE 4.6. SUMMARY OF VALUES RELATED TO
GROWING SEASON THERMAL REGIME

Key to stations and positions
(degrees and minutes N, W)

ML-Meadow Lake ^a	54 08, 108 26
BN-Buffalo Narrows	55 51, 108 30
FF-Creighton ^b	54 45, 101 54
LR-La Ronge	55 06, 105 17
CH-Cumberland House	53 58, 102 16
SB-Sandy Bay ^c	55 33, 102 18
WD-Whitesand Dam	51 27, 102 40
BL-Brabant Lake	56 00, 103 43
CL-Cree Lake	57 22, 106 50
UC-Uranium City	59 34, 108 36
SR-Stony Rapids	59 16, 105 50
CB-Collins Bay	58 17, 103 39

^a peripheral to study region
^b recording station at adjacent Flin Flon
^c recording station at adjacent Island Falls

Variable	Stations											
	ML	BN	FF	LR	CH	SB	WD	BL	CL	UC	SR	CB
<hr/>												
frost-free days												
1.	111	129	----	104	----	103	94	----	100	108	89	----
2.	115	110	----	90	110	104	92	----	106	109	73	----
growing degree days (GDD)												
3.	1340	1189	1294	1165	1380	1119	970	1024	1089	1022	875	716
4.	1359	1194	----	1148	1386	1150	1034	----	978	1085	948	----
5.	1071	1135	----	925	----	939	777	----	879	974	716	----
6.	659	606	----	442	----	508	309	----	282	555	142	----
photothermal units (PTU x 100)												
7.	209	189	203	185	215	177	154	162	157	167	142	116
8.	131	138	----	114	----	113	94	----	106	117	89	----

Sources

1. Determined from daily minimum temperatures for years of complete record. Records 15 years or more except SR (5 yrs), BN (8 yrs), & CR (12 yrs).
2. Wheaton 1979.
3. Determined from mean monthly temperatures (1951-80). Base 5°C.
4. As in 2. Base 5°C.
5. As in 1. Values are "minimum accumulated GDD". Base 0°C.
6. As in 5. Base 5°C.
7. As in 3. Employs monthly mean day length for station latitude.
8. As in 1. Values are "minimum accumulated photothermal units". Base 0°C.

Figure 4.3. Mean frost-free period.

Accumulated heat is shown as GDD in Figure 4.4 (interpolated from rows 3 and 4 in Table 4.6). Values range from about 1300 GDD near the NAD boundary in the south to less than 900 GDD north and east of Wollaston Lake and Stony Rapids. Note that a fairly close coincidence is seen between the 1000 GDD line and the line for 100 frost-free days. Figure 4.5 depicts the distribution of photothermal units (from row 7, Table 4.6) and strongly resembles the GDD pattern. A decline of over 600 PTU occurs, from 20,000 in the south to under 14,000 in the northeast. In this case the 16,000 PTU isoline is quite similar to the 100 day line in Figure 4.4.

Earlier incidence of fall frost should accompany the northeastward progression toward a shorter season and cooler regime. For example, La Ronge and Stony Rapids are relatively distant stations along the climatic gradient. Mean fall frost dates were determined to be September 7 (Julian day 251.24; standard deviation 12.92) and August 24 (Julian day 237.20; standard deviation 12.77) respectively based on the aforementioned daily minimum temperature data set. The harvest onset data for the La Ronge area revealed that mean date of wild rice maturity is August 26 (Julian day 239.00; standard deviation 5.77). Thus the probability of frost preceding seed maturation, thereby causing serious crop

Figure 4.4. Mean growing degree days (GDD)

Figure 4.5. Mean photothermal units (PTU)

damage, should be greater at a location such as Stony Rapids.

If the frost and maturation events are assumed to be independent and normally distributed then the probabilities may be depicted as in Figure 4.6. The graph consists of cumulative relative frequencies portrayed against time. Line PWRM represents the probability, for a given date, that the wild rice crop has not yet matured enough for harvest to commence. Lines PFSR (Stony Rapids) and PFLR (La Ronge) give the probability that the first fall frost has already occurred. For each station the overall magnitude of severe frost damage risk is given by the area beneath the intersecting curves. Summing the daily products of the separate probabilities (i.e. wild rice not mature yet, but frost does occur) provides estimates of the crop loss risk. The value calculated for La Ronge was 18.5%; for Stony Rapids the value, at 42.9%, was notably higher.

4.3 Overview of Intraregional Potential

By incorporating the findings of other research into the classification (ELC) approach, it was possible to subdivide the study region into wild rice growing districts. In particular, Liaw and Atton (1981) described a southwest to northeast gradient of declining waterbody nutrient status in

PROBABILITIES

- Wild rice not mature
- Frost at Stony Rapids
- - - Frost at La Ronge

CROP FAILURE RISK

- 42.9%
- ▨ 18.5%

Figure 4.6. Probability curves used in estimation of risk of severe frost damage to wild rice crops. The comparison is for La Ronge and Stony Rapids.

the northern portion of the province. Isolines of total dissolved solids (TDS), a measure closely correlated with conductivity in fresh waters, showed 3 major zones north of the NAD boundary. These were also associated with progressive reductions in total alkalinity and pH. In the area between the NAD boundary and a line approximating the Shield margin TDS values generally range from 200 down to 100 mg l⁻¹ (approximately equal to conductivity of 320 to 160 μ S cm⁻¹). Mean pH and total alkalinity for this area are given as 8.01 and 124 mg l⁻¹ (as CaCO₃) respectively.

The Shield is presented as an area where TDS is generally less than 100 mg l⁻¹, including 2 distinct zones. In the more southerly zone mean TDS, pH and alkalinity are 76 mg l⁻¹ (conductivity about 122 μ S cm⁻¹), 7.39 and 38 ppm respectively. A 50 mg l⁻¹ TDS isoline is shown more or less parallelling the Shield margin and following a course essentially similar to that seen for the 17,000 PTU line in Figure 4.5, except that it skirts the perimeter of Lake Athabasca. Waters to the north and east are characterized by the mean values: TDS 40 mg l⁻¹ (conductivity about 64 μ S cm⁻¹), pH 7.12 and alkalinity 15 mg l⁻¹). The differences are ascribed to the combined effects on water quality of climate and surficial geology.

Many aspects of regional hydrology, including drainage patterns, stream gradients and lake densities, as well as basin forms are dependent upon physiography and landform genesis. Koshinsky (1970), investigating Shield lakes in particular, found that despite wide ranges in surface dimensions various measures of morphometry could be shown to be linearly (log transformed) related to surface area. As size increased basins tend to become less "U-shaped" and to have more islands and increasingly more complex shoreline configurations. The relationship was explained in terms both of the predominance of glacial ice scour in basin formation and the undulating nature of the Shield terrain.

Elongation of lake basins in response to the orientation of geological structure is cited as a factor favouring wind-induced circulation currents. In the classification process lake size and configuration, because they are features readily apparent on maps and Landsat imagery, were important criteria. The relevance to habitat potential for wild rice lies in the fact that proportion of surface water area situated over the littoral (shallow) zone is greater when lakes of a particular size are either less U-shaped or more sinuous in shoreline form. Conversely, for lakes of a given configuration, the restrictions imposed on wild rice viability by wave action and normal fluctuations in water

level are expected to be greater as lake size increases.

The result of the classification of the region into districts is shown in Figure 4.7. The portion excluded as not feasible for long term, successful production constitutes approximately 98,750 km² (33.2%) of northern Saskatchewan. A northern margin for wild rice habitat suitability was set primarily on the basis of the climatic analysis provided earlier. The margin conforms closely to the 15,500-16,000 PTU band shown in Figure 4.5. It was recognized, however, that adverse effects of thermal regime may be additive to those of other habitat factors, creating significant environmental stress. On the remaining 198,250 km² (66.8%) a total of 27 districts are identified. Table 4.7 lists the relative proportion of the total area suitable for wild rice comprised by each district, while descriptions and comparisons of potential for providing wild rice habitat are found in section 5.3.

The scheme strongly reflects the major physiographic units in the region. Districts S1 to S10 (inclusive) are situated on the scoured granitic/volcanic/metamorphic bedrock areas of the Shield. Relatively higher densities of lakes with irregular shorelines are found, but they tend to be characterized deeper (more U-shaped) and of lower nutrient

status. The AS1 to AS4 (inclusive) districts coincide with the late Precambrian Athabasca Sandstone basin, also a part the Shield, where lake densities are lower.

Except for the SP1 district, which is considered to be situated astride the Shield margin, the other districts together define that portion of northern Saskatchewan comprised of drift deposited on sedimentary bedrocks. Lowlands (L1 to L4) and plains (P1 to P4 and PL1) are prevalent, although there are 3 areas of hilly uplands (U1 to U3) as well. Lake densities vary considerably in the lowlands/plains and are quite low in the upland districts.

Figure 4.7. Classification of the study region into wild rice districts

TABLE 4.7 AREAL EXTENT OF DISTRICTS

<u>District</u>	<u>Area (km²)</u>	<u>%of Total Area¹</u>
AS1	9,091	4.6
AS2	11,516	5.8
AS3	15,607	7.9
AS4	6,211	3.1
S1	17,198	8.7
S2	4,318	2.2
S3	5,455	2.8
S4	3,023	1.5
S5	7,045	3.6
S6	9,773	4.9
S7	6,970	3.5
S8	9,925	5.0
S9	5,757	2.9
S10	5,000	2.5
L1	3,789	1.9
L2	3,789	1.9
L3	7,500	3.8
L4	4,545	2.3
PL1	11,061	5.6
SP1	6,591	3.3
P1	4,166	2.1
P2	3,789	1.9
P3	5,302	2.7
P4	6,364	3.2
U1	10,909	5.5
U2	11,743	5.9
U3	1,818	0.9
Total	198,255	100.0

¹refers to combined area of that portion of region classified as suitable for wild rice

Chapter 5

DISCUSSION

5.1 Wild Rice Habitat and Growth Performance

While values for most of the variables ranged quite broadly, reasonable agreement with the literature was obtained. Differences in methods restrict the amount of comparison. Water depths essentially spanned the range suggested by Dore; mean depths somewhat less than 1 m are also reported elsewhere. The water pH range corresponds well with those given by Lee and Stewart (1981), Archibold and Weichel (1983) and Garrod (1984). Both lower (Lee and Stewart 1984) and much higher (Garrod) values for water conductivity have been recorded. Further, values for pH and for phosphorus content of sediment are in accordance with those given by Lee and Stewart (1983) as well as by Peden (1982).

Certain more specific comparisons are possible with respect to several of the wild rice plant variables. For instance, in the on-Shield data (Table 4.6), values may be found for number of female florets (22.1), stem unit weight (1.1 g m^{-1}), leaf width (11.3 mm) and productivity index (27.6). The pertinent values from 11 sites on the Shield in

Ontario (Counts 1984) are estimated (by the present author) as 30.2, 1.1, 9.9, and 31.0 respectively. Reported ranges in number of female florets per panicle, 11 to 120 (Lee 1979) and 4 to 163 (Garrod), are very similar to the 6 to 153 found for this region. In Saskatchewan the regional mean for number of female florets is slightly lower and dry weight per seed slightly higher than in more southerly locations. Garrod joins Lee in attributing a northward decline in floret number (coincident with greater seed size) to greater prevalence of the variety palustris (Northern wild rice or "lake rice"), while Counts (1983) implicates the effect of changing climate on accelerated maturation.

The question of whether both varieties of Z. palustris may be identified in northern Saskatchewan had initially been considered important; phenotype under any particular habitat conditions is linked to genetic potential. The variety palustris had been assumed to be predominant, although Dore (1969) reported that the variety interior (Interior wild rice or "river rice") was present in the western area, southeast of Buffalo Narrows. The results do not provide an exceptionally clear answer to the question as posed. From the morphological characteristics of plants in the Buffalo Narrows vicinity it could be concluded that both varieties are indeed found in the province. Dore reports that variety

interior may typically have 25 to 35 mm wide aerial leaves, 10 to 30 female florets per panicle branch, and stem lengths in excess of 200 cm for plants situated in water of less than 30 cm depth. The largest specimens retrieved were from water of 25 cm depth at site 28 on the Beaver River and, although taken as incidental collections outside sample stations, provided measurements of up to 19 florets per branch, 36 mm leaf width and 282 cm stem length.

The issue of taxonomically distinct varieties is clouded by the variability encountered in both habitat conditions and plant performance. Phenotypic expression in wide-ranging (genetically heterogenous) species can be the result of plasticity in response to local environment. Wild rice from a single source might thus produce more "river-rice-like" plants in stream sites and more "lake-rice-like" plants when introduced into small lakes and bays. Productivity and morphology variations may then be anticipated along various possible habitat clines; environmental factors which evidently exhibit cross-regional gradients would be exerting independent or synergistic effects which account for the recorded differences in growth. Barbour et al. (1980) argue that the concept of a continuum of variation, or ecocline, is more appropriate for plant ecology than the idea of discrete taxonomic varieties. While the varietal question may be

invalid, broad morphological variation was found in this study and further research, including mutual transplants, would help clarify the role of phenotypic plasticity.

The results confirm what Dore (1969) suggested, that enhanced wild rice growth will be found in stream channels and mouths where there is continuous flow or circulation of water. He had further predicted reduced performance found in waters on the Precambrian Shield. In this study the locational component (habitat framework) provided significant explanation of intraregional growth variations. These in turn can be partly accounted for by correlations with certain habitat factors. Selected bivariate correlation coefficients are shown in Table 5.1. Included is a derived location variable for geographic position (GP) representing sampling station position along a southwest to northeast geographic transect; highest GP values were therefore assigned to the most northeasterly stations. In this way location can be expressed in a linear fashion.

The relationships between the water and plant variables support the contention that these habitat measures do correspond to wild rice performance, although predictive usefulness is impeded by the low coefficient values. Stem density and seed weight were not correlated with water

TABLE 5.1. PEARSON CORRELATION COEFFICIENTS FOR
SELECTED HABITAT AND WILD RICE VARIABLES

	Stem density	Female florets	Stem unit wt.	Prod. index	Seed wt.	Leaf width	# tillers	Biomass	Geographic position ¹
Water Depth	.01	-.57**	-.55**	-.58**	-.04	-.56**	-.52**	-.28**	.54**
Water pH	-.05	.22**	.32**	.23**	-.08	.17*	.19**	-.07	-.51**
Water Conductivity	.02	.35**	.41**	.36**	-.02	.30**	.24**	.14	-.65**
Water Alkalinity	.03	.35**	.39**	.34**	.02	.34**	.26**	.28**	-.66**
Sediment NH ₄ -N	-.04	-.03	-.12	-.03	-.03	-.04	.13	-.07	.12
Sediment NO ₃ -N	-.04	-.14*	-.16*	-.15*	.04	-.13	-.15*	-.01	.02
Sediment P	-.02	.10	.14*	.10	.23**	.06	-.07	.42**	-.26**
Sediment K	-.12	-.27**	-.37**	-.28**	-.17*	-.34**	-.25**	-.26**	.58**
Geographic Position _i	-.03	-.50**	-.56**	-.50**	-.21**	-.48**	-.41**	-.32**	---

* p < .01 ** p < .001

¹The geographic position (GP) variable provides a discrete measure of relative location of sampling stations from southwest to northeast. The direct line between extremities in the overall sampling zone was subdivided into equal intervals; bands were drawn oriented perpendicular to the direct line. Stations situated in the southwest-most band were assigned the lowest GP value while the highest value was given to stations furthest northeast.

conditions. As a group the significance of the sediment macronutrients is much less. The apparent negative correlation of potassium with wild rice performance is not understood. Other authors (Lee 1979; Peden 1982; Atkins 1984; Archibold and Weichel 1983) have had only limited success in clarifying the role of sediment chemistry in determining seeding success and growth in lakes. In many cases this may be due to the presence of nutrient levels in excess of plant requirements. Phosphorus concentrations are considered quite important (Lee and Stewart 1984; Garrod 1984) but this element is seen to be positively correlated only to seed weight and biomass. With the exception of sediment nitrogen and stem density the remaining habitat and plant measures listed in Table 5.1 are significantly correlated with the GP variable. The relationship indicated is one of a cross-regional (northeastward) decline in water nutrient status coincident with reduced individual wild rice plant performance.

5.2 Regional Climate

The spatial and temporal scarcity of climatic records and phenological information for the region restricts interpretation of the results. However, the findings are useful in characterizing the regional temperature environment

and provide a basis for determining the extent to which climate may be a limitation for wild rice production in northern Saskatchewan, in part by comparison with the situation outside Saskatchewan.

Most wild rice research in Minnesota is conducted on special (nonshattering) varieties grown in artificial paddies. Phenology studies there (Grava et al. 1977-82) found that spring-planted wild rice matured in a mean period of 109 days after an accumulation of a mean of 1450 GDD (present author's estimate). This is on the order of 20-25% more than the 1150-1250 GDD shown for the major Saskatchewan production zone extending from Creighton through La Ronge to Buffalo Narrows (Figures 2.3 and 4.4). Some part of that difference is undoubtedly due to the limited accuracy of the procedures necessitated in the present study. The distribution of known wild rice stands in the region (Figure 2.3) shows very few situated northeast of the 1050-1100 GDD band (Figure 4.4). Evidence from Manitoba (Stewart 1984) and Ontario (Lee and Stewart 1984) is supportive. When heat accumulation in those areas is similarly estimated there are no stands known beyond the 1100-1150 GDD band.

Temperature affects plant growth mainly through its influence on rates of various metabolic reactions, while

hours of daylight largely control daily duration of photosynthesis. Since both are growth determinants it is appropriate, in comparing latitudinally distant areas, to employ photothermal units. A mean of approximately 21,200 PTU (present author's estimate) accumulated in the abovementioned average 109 day life cycle of wild rice in an area of Minnesota situated at around 47° north. Northeasterly outliers in the Ontario stands mapped by Lee and Stewart (1984), in the vicinity of 52° N, 89° W, would be growing under an estimated mean accumulation of approximately 17,500 PTU. The majority of Saskatchewan wild rice is presently found between 54° and 56° N; PTU values in that latitudinal zone are mainly in the 17,000-20,000 range, with virtually all known stands located southwest of the 16,000 PTU isoline (Figures 2.3 and 4.5). The rough comparison between Saskatchewan and Minnesota therefore reveals that approximately 10-15% less PTU's are available in the study region, or about half the difference found when GDD values are used in the comparison. Nuttonson (1957) noted a similar relationship for spring wheat; accumulation requirements diminished with increasing latitude but the PTU measure provided the least amount of variation.

The conclusion that, in northern Saskatchewan, wild rice matures under a more stringent thermal regime than in more

southerly areas is consistent with expectations. Counts (1983) discusses a latitudinal gradient of northward acceleration through growth stages concurrent with decreases in seed numbers and plant size. Phenological study of other species shows that the time required for a particular phenophase is a relatively constant fraction of the available annual heat accumulation for the latitude at which a plant is growing (Reader 1983). While more research may provide confirmation, there is a small amount of data to link reduced wild rice growth performance to diminishing heat accumulations (Counts 1984).

The existence of a significant climatic limitation for wild rice growth in portions of northern Saskatchewan is supported by the evidence presented. More detailed analysis is precluded by the current paucity of data. However, the supposition that the thermal character of the region may be used as an environmental factor in identifying potential habitat is realistic. No attempt has been made to determine whether the climatic factors operate in concert with other habitat conditions. On the basis of climate alone (ignoring the effects of intraregional differences in water chemistry etc.), the northern margin of suitable habitat should be approximated by the 15,500-16,000 PTU band (Figure 4.5). Due to isoline orientation and curvature the 16,000 PTU line

extends much further north on the west side of the province, intersecting the northern boundary at 60° N near $108^{\circ}30'$ W. This implies that wild rice growth would be feasible in the area north of Lake Athabasca. In fact, the author has examined specimens retrieved from the vicinity of Uranium City in 1983; these plants were quite spindly however, and bore few female florets.

Inherent climatic variability could allow short term successes in establishing stands some distance northeast of the 15,500 PTU zone. The estimation of severe crop loss due to early fall frost incorporates the element of probability. Barring the future development of earlier-ripening strains, such risk warrants consideration in assessing the viability of seeding wild rice in marginal locations. The 18.5% value obtained for La Ronge predicts the occurrence of serious harvest reductions due to frost as slightly less than a once in 5 years event. For Stony Rapids the 42.9% value indicates chances on the order of once in 2 to 3 years, which may be considered excessive in economic terms even if not actually prohibitive in ecological terms. It remains to be shown whether the assumption of independence of the frost and seed maturity events is valid. Another possibility is that abnormally cool growing seasons will be accompanied by both later wild rice maturation and earlier frost incidence. In

those circumstances the above risks would constitute underestimates.

5.3 Overview of Intraregional Potential

This component of the study represents an amalgamation of information concerning wild rice habitat requirements together with the environmental heterogeneity of northern Saskatchewan. The results permit only broad description and wholly qualitative assessment of how the potential for growing wild rice is distributed within the region. The outcome is depicted in Figure 5.1 and also described in Table 5.2. The latter includes a subjective rating of relative capability for the 27 identified districts, as well as an indication of the general limitations involved.

As with the northeastern one-third of the region, AS4 is deemed to have no potential; 35.3% of the total regional is thus unlikely to make any significant contribution. The 3 districts rated as having very low capability are located on the Athabasca Sandstone portion of the Shield and constitute 12.3% of the region. A total of 20.9% is rated of low capability. For the 5 more northeasterly Shield (S) districts the negative effects of climate and water nutrients are offset by lake densities; the converse is true for 3 upland

Figure 5.1 Distribution of capabilities to provide wild rice habitat

TABLE 5.2. SUMMARY OF INTRAREGIONAL CAPABILITY AND LIMITATIONS FOR WILD RICE

<u>CAPABILITY</u>	<u>DISTRICTS</u>	<u>% OF AREA</u> ¹	<u>DESCRIPTIONS AND LIMITATIONS</u>
Nil	AS4	3.1 (2.1)	This district encompasses the majority of Lake Athabasca, the largest lake in the province. The assumed lack of habitat potential stems from very low availability of sites sheltered from wave action, large fluctuations in water level and the marginal position with respect to climate.
Very Low	AS1, AS2, AS3	18.3(12.3)	The Athabasca Sandstone, thinly overlain by sandy tills and glaciofluvial deposits, dominates all 3 districts. Very low nutrient status and the climate are considered to be the chief limitations, but are somewhat more important for districts for AS 1 and AS 3. All have moderately low densities of small lakes.
Low	S6-S10 (incl.)	18.8(12.6)	These districts are expected to be the least productive of those on the non-sedimentary areas of the Shield. Overburden of glacial drift is thin and discontinuous. Climate and water quality are significant limitations. PTU values are less than 17,000; nutrient status is low as described in subsection 4.3. With the exception of S8 the districts have fairly high densities of lakes with irregular outlines. However, extent of littoral zones may be reduced by the scoured form of basins.
	U1, U2, U3	12.3(8.3)	These upland areas consist mainly of morainic tills and sandy outwash deposited on elevated sedimentary plateaus and their escarpments. The major limitations are considered to be low densities of lakes and/or slow-flowing streams.
Moderate	S1-S5 (incl.)	18.8(12.6)	Terrain composition is similar to that of districts S6-S10 above, but nutrient status and climate are deemed to be more favourable than the former. Water quality conditions are in the higher of the 2 groups described for the Shield in subsection 3.3, while PTU values should exceed 17,000. In districts S1 and S2 a negative factor may be proportionally less shelter due to lake sizes. Water level fluctuations could also be a factor along the lake chain forming the Churchill River.
	L1, L2, L4	6.1 (4.1)	The lowlands encompassed by these districts are comprised of glacio-lacustrine/alluvial deposits (L1, L2) or sandy till and outwash (L4) over post-Precambrian sedimentary bedrock plains. L1 includes the broad inland Cumberland Delta of the Saskatchewan River. Waters in this district have relatively higher dissolved mineral contents and turbidities, and may undergo wide fluctuations in level. Sheltered sites free of perennial aquatics may be scarce. L2 has low density of water bodies as a limitation. Potential for district L4 is decreased by the high proportion of surface water occurring as large, open lakes (therefore few sheltered sites) and by water level fluctuations.

TABLE 5.2. (continued)

CAPABILITY	DISTRICTS	% OF AREA ¹	DESCRIPTIONS AND LIMITATIONS
Moderate (cont.)	P1	2.1 (1.4)	An upland area of sandy till and outwash deposits over sedimentary bedrock. The principal limitation is considered to be a high proportion of moderate-sized, open lakes with unconvoluted shorelines offering few sheltered sites.
High	L3	3.8 (2.5)	Till and glacio-lacustrine deposits are thinly overlain on scoured sedimentary bedrock which is locally exposed. Amount of adequately sheltered sites free of perennial aquatics is the main restriction as lake outlines are not especially irregular. In some instances waters may contain excessively high levels of dissolved minerals. Sluggish streams in the district may afford the best sites.
High	P2, P3, P4, PL1	13.4(9.0)	These districts consist largely of outwash and sandy till mantling sedimentary bedrock. Water level fluctuations and availability of sheltered sites are deemed to be the major restrictions on habitat potential. Lake density is also relatively low, particularly in P2.
High	SP1	3.3 (2.2)	This district is situated astride the Shield margin and thus consists of till overburden on sedimentary rock grading northward to extensively-exposed Precambrian bedrock. Nutrient status of water is enhanced by a significant amount of drainage from off-Shield directions. Lake density is fairly high, but availability of sheltered sites and water level fluctuations will be important factors.

¹percent of: subregional area considered suitable for wild rice (total area in region)

districts along the southern limit of the region. Moderate capability is assigned to 18.1% of the total area. The negative effects climate and nutrient status are not expected to be as important in the 5 more southwesterly Shield (S) districts and, as in 4 off-Shield lowland/plain districts, water level fluctuations and availability of sheltered sites will become relatively more limiting. Finally, only 13.7% of the region is considered to have a high capability for providing wild rice habitat. Six off-Shield districts, 4 of them situated along the Shield margin, are considered to have an optimum mixture of suitable environment and site availability.

The classification provides a tentative framework to be tested in use and revised as knowledge and experience allow. By evaluating the comparative contribution of the various districts to the wild rice industry as a whole, it should prove useful in administration of permit applications and in monitoring the spread of wild rice throughout the region. Undoubtedly the location of settlements and road access routes are partly responsible for the current pattern of activity, although approval and cancellation of permits are ongoing (Oberick, pers. comm.). However, reference to figures 2.2, 2.3 and 5.1 reveals that there has been a concentration of both permits and established stands in districts generally

more highly rated. One consequence, in terms of efforts to increase the established crop area, is that much of the relatively "unused" portions of the region have lower potential for providing suitable habitat.

Chapter 6

SUMMARY and FURTHER RESEARCH

The outcome of this study should be viewed in the context of its essential purpose. Put simply the question -- "How much wild rice habitat is there in northern Saskatchewan and where is it located?" -- provided the basic direction. The overall goal was to create a foundation upon which that question might be answered. Since it is often difficult to assess the extent to which uncolonized habitat is suitable, occupied habitat must serve as the definitive base (Ayal and Safriel 1983). Evaluating habitat potential also entails extrapolation; what is known about the niche of the species must be superimposed on what is known about the availability of such a niche in the region of interest.

By examining established stands at widely separated locations it was found that certain environmental conditions differed significantly between major categories of habitat. Similarly, wild rice growth performance was significantly better in some locations. Stream sites were more productive than lake sites, and on the Precambrian Shield the plants were notably less robust than those situated south of the Shield margin. An eastward or northeastward gradient of

declining performance was found and was shown to be significantly correlated with habitat variables, principally those related to the nutrient status of water.

The province's wild rice populations are apparently genetically heterogenous. Examples fitting the taxonomic descriptions of both Z. palustris var. palustris (Northern wild rice or "lake rice") and Z. palustris var. interior (Interior wild rice or "river rice") were found. It is not presently known to what degree phenotypic expression reflects differences in genetic potential rather than plastic response to environment. However, it now seems more appropriate to invoke the ecocline concept to explain morphological and productivity variations as part of a continuous gradation between different habitat types or distant locations.

An increasingly unfavourable growing season is discernible along a gradient from southwest toward the northeastern portion of the region. In terms of thermal or photothermal accumulations over the season, existing northern Saskatchewan wild rice crops mature under a slightly more stringent regime than those in northwestern Ontario and northeastern Minnesota. However, a curved margin of probable climatic feasibility has been drawn, transecting the region to exclude the northeastern one-third. Stands in the

productive central area south of the Churchill River have, on average, matured by August 26. The chance of severe damage due to early frosts was estimated as being on the order of 15-20% in that part of the region. Northeastward, in the general vicinity of Wollaston Lake, the risk is thought to be closer to 40-45%.

Within the two-thirds of northern Saskatchewan deemed suitable for wild rice, consideration has been given to variation in environmental factors that affect the quality and availability of potential habitat. Twenty-seven districts have been delineated. A general assessment of capabilities and limitations groups the districts into broad categories. A rating of moderate or high potential was assigned to 15 districts encompassing approximately 32% of the total area of the region; the remaining 12 districts account for about 35% of the area and are rated nil to low. Concentration of activity thus far has been in more accessible areas, close to settlements in the districts along or south of the Precambrian Shield margin, with less proliferation into the lower rated districts.

Neither quantitative estimates of actual hectares, nor maps of specific sites suitable for seeding, can as yet be readily and accurately made. Locating possible new sites is

currently a haphazard process carried out by growers or would-be growers who generally rely on failure of seeding efforts to eliminate candidates. A regional scale inventory would require an effective method of applying the habitat definition. Therefore, as a logical subsequence to the present study, a preliminary investigation was conducted into the feasibility of using satellite remote sensing as an inventory method (Welchel and Archibold 1985).

The trial involved loading Landsat digital data for a selected image area into a Dipix ARIES II Image Analysis System. The equipment allows operator interaction and several statistically-derived classification procedures to develop spectral signatures for mapping surface features. Fifteen test sites which could be designated as suitable habitat for wild rice were located on the 1976 image. Successful plantings after 1976 provided proof such designation was valid. A signature was developed on each of two lakes which gave optimum separation between the portion now supporting wild rice and the rest of the lake.

Inherent problems with the technique include the low (80 m) resolution of the early Landsat scanners and the fact that penetration of water is comparatively poor. However, since the investigation was preliminary, the success in having the

signatures identify predefined test areas as suitable habitat was encouraging. Used in conjunction on all 15 sites the signatures classified from 7% to 65% (mean = 32%) of the designated hectares as capable of supporting wild rice (Figure 6.1). The system was also shown to be useful for rapidly discriminating between land and open water to find the extent of water bodies on the image or any subarea. In addition to areal determinations, outputs from the digital analysis include statistical summaries and maps at a variety of scales.

Further research into variations in wild rice morphology and phenology is ongoing. One objective is to determine how success might be enhanced by matching habitat conditions more closely. For example, in seeding deeper water lake sites it may be best to use seed from plants which are consistently most productive in such a setting, while in climatically marginal areas earlier maturity would be an obvious asset. An improved understanding of phenotypic plasticity in wild rice is therefore needed, including the effects on growth and productivity of interchanging plants from various locations. Initial results (Archibold and Weichel 1984) substantiate the conclusions in the present study concerning the positive correlation of greater productivity with shallower waters of higher pH and conductivity. Also, though hampered by the

Figure 6.1 Example of trial use of digital Landsat data to identify potential wild rice habitat

The photograph shows a false colour display on video monitor of Merritt Lake (near 103° 40' W, 54° 50' N) recorded on a June, 1976 Landsat 2 image. Depicted is the result of using spectral signatures for suitable wild rice habitat to classify water in the scene. The classification was done by the Dipix ARIES II system with an unsupervised statistical (maximum likelihood) routine. The signatures were developed for two other sites known to support wild rice; the plant was absent from Merritt Lake in 1976 but has since been very successfully introduced. The small squares visible in the photo are the pixels, or minimum resolution elements, in the scene and are equivalent to approximately 0.44 ha (56 m X 79 m). A medium blue outline encircles the area predefined as habitat. Yellow pixels are those classified as habitat while black pixels are unsuitable open water areas. A total of 45% of the lake was classified as suitable for wild rice, as were some parts of the stream channel flowing into (from the left) and out of (center bottom) the lake. An aerial photo (forest inventory collection) of similar vintage showed that the yellow areas in this display would generally correspond to shallow water with a moderate density of water lilies.

paucity of recording stations for climatic data, cross-regional differences in phenology have been recorded that are thought to be related to differences in the thermal regime. Additional study is underway into nutrient content of sediments from lakes throughout the principal wild rice growing areas of the region. A preliminary review of this data (Archibold 1985) lends support to present findings regarding distribution of macronutrients.

Substantial progress has been made in this study, as well as in the related research described above, toward an improved understanding of the potential magnitude and extent of the wild rice industry in northern Saskatchewan. Clearly the social, economic and environmental impacts of the proliferation of this introduced plant will not be uniformly distributed. The latter, particularly the effects on other aspects of aquatic communities, remains to be seriously investigated and must given a higher priority the regulatory agencies. When that occurs it is hoped that the foregoing will serve both as a base of knowledge and a means of focussing future enquiry.

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